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INFORMAL REPORT

THE MERCATOR PROJECTION AND ITS VARIATIONS

MICHAEL G. PARADIS
Project Control Staff
Office of the Director
Technical Production Department

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ABSTRACT

This report presents basic information on the Mercator Projection, including its variations, and a selected glossary. The report is aimed at the apprentice cartographer as well as non-professional personnel whose duties require a familiarity with projections in general. The method of presentation, supported with illustrations, is intended to comprehensively depict the intrinsic properties of each projection covered.

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MERCATOR

Gerhard Kremer (Gerhardus Mercator) was a Flemish geographer who was born in 1512 at Rupelmonde in East Flanders. He is primarily recognized for the Mercator Projection which bears his name in the Latinized form. For this achievement, he ranks as the greatest cartographer-geographer of his time.

Mercator was neither the inventor nor the first user of a rectilinear type projection, but much like Henry Ford with the automobile, combining presentation with practicability, he was the first to successfully apply it in an empirical manner to a nautical chart.

Mercator received his formal education at the University of Louvain. He studied mathematics, astronomy, and cosmography. He also interned in the production of scientific instruments. Upon receipt of his master's degree he stayed on at Louvain as an instructor of mathematics, and might have remained in this position had his beliefs not fallen in line with Protestant teachings, a very unhealthy position at that time. Fortunately, Mercator was not executed along with other Protestant believers, and he lived to develop the projection which has yet to outlive its usefulness in the field of navigation.

Upon departing the university, Mercator shifted his interests to the cartographic realm, a field in which many members of his family had earned their way. Although little known today for his cartographic ability, Mercator excelled in surveying, engraving,

and map making. He produced celestial and terrestrial globes, charts, and numerous maps, few of which exist today.

The accomplishment for which Mercator is most famous occurred around 1550, when a world chart produced by him portrayed a graticule in which the spacing between the lines of latitude increased toward each pole, the lines of longitude were equally spaced, and both sets of lines were mutually parallel. Mercator had arrived at the solution of a major problem in navigation, that of navigating with straight rhumb lines. In order to produce straight rhumbs he straightened the meridians empirically; however, this shift introduced distortion of both distance and direction relationships. Above all, he desired to retain the direction relationship. So, to compensate, he extended the distances between parallels at an increasing rate from the equator to the poles.

MERCATOR PROJECTION

The Mercator Projection is a rectilinear projection and the only projection in which the loxodrome (rhumb line) is delineated as a straight line. For ease of explanation it may best be described as a projection developed on a cylinder (see Figure 1) whose surface is tangent to that of the earth along the equator, whose axis is coincident with the polar axis, and whose point of view is the center of the earth. In reality the Mercator projection can only be constructed through mathematical computation or from published tables that have been derived mathematically.

CYLINDER TANGENT AT THE EQUATOR

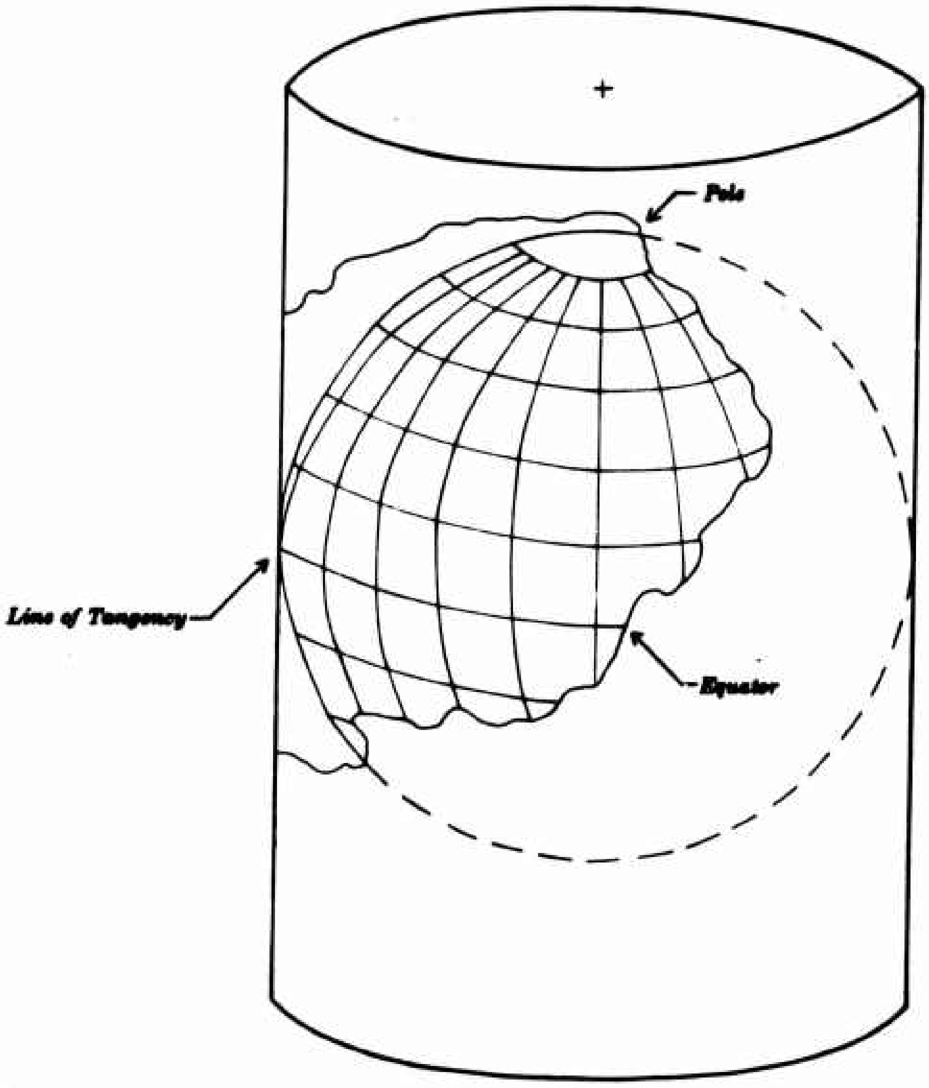


Figure 1

There are numerous advantages and also disadvantages related to the Mercator Projection. These features are intrinsic to the projection. Among the advantages, the first and foremost may be said to be a straight rhumb line portrayal which makes the navigator's job of course determination relatively easy. He can readily transfer great circle routes from a gnomonic projection (which delineates great circles as straight lines) onto his Mercator chart as a series of connected rhumb lines, and thus steer the shortest course. A second advantage is that the projection is conformal, that is, land forms retain a similar shape to those they represent on earth. A third advantage is that the projection is easily constructed from readily available tables. An example of the Mercator's ease of calculation and construction may be observed in Figures 2 and 3, respectively.

There are three major disadvantages, the first being the distortion in size which is present over large areas. While still retaining the correct shape, areas are extremely exaggerated on approaching the poles. Due to this distortion the projection is practically useless beyond 80° of latitude. The second undesirable feature is that of lack of constant scale; on the Mercator, the scale varies from parallel to parallel and point to point, and the navigator must compensate for these variances when using the projection. An example of the variation of scale is exhibited in Table 1. The third disadvantage of the Mercator Projection is that great circles appear as curves and must be plotted from other

MERCATOR PROJECTION COMPUTATION

MERCATOR PROJECTION COMPUTATION
PRNC-NHO-3161/16 (Rev. 6-56)

CHART NO. **Figure 3**

(Arc of Parallel / Polyconic tables) 1' of longitude at latitude 00°00' = 1855.3 meters

Scale: 1' of longitude = 1855.3 m.X100/Scale = .0017754 centimeters

(Originally given as 1: 104,500,000 at Lat. 00°00' N.)

Bottom Par. 00°00' Western(~~Eastern~~)Meridian 150°W

Top Parallel 80°00'N Eastern(~~Western~~)Meridian 30°W

Whole extent of Lat. in centimeters 14.82845, in inches 5.83797

Whole extent of Long. in centimeters 12.78288, in inches 5.03263

Diagonal = $\sqrt{(\text{Lat. extent})^2+(\text{Long. extent})^2}$ = 19.57766 centimeters

LATITUDE NORTH	MERIDIONAL DISTANCES	MERIDIONAL DIFFERENCES	DIST. FROM BOTTOM PAR.	DIST. FROM TOP PAR.	D^1	D^2
00°00'	000.000	---------	------	14.82845		
10°00'	599.019	599.019	1.06350	13.76495		
20°00'	1,217.159	1,217.159	2.16094	12.66751		
30°00'	1,876.706	1,876.706	3.31319	11.51526		
40°00'	2,607.683	2,607683	4.62968	10.19877		
50°00'	3,456.581	3,456.581	6.13681	8.69164		
60°00'	4,507.133	4,507.133	8.00196	6.82649		
70°00'	5,943.955	5,943.955	10.55290	4.27555		
80°00'	8,352.176	8,352.176	14.82845	-------		

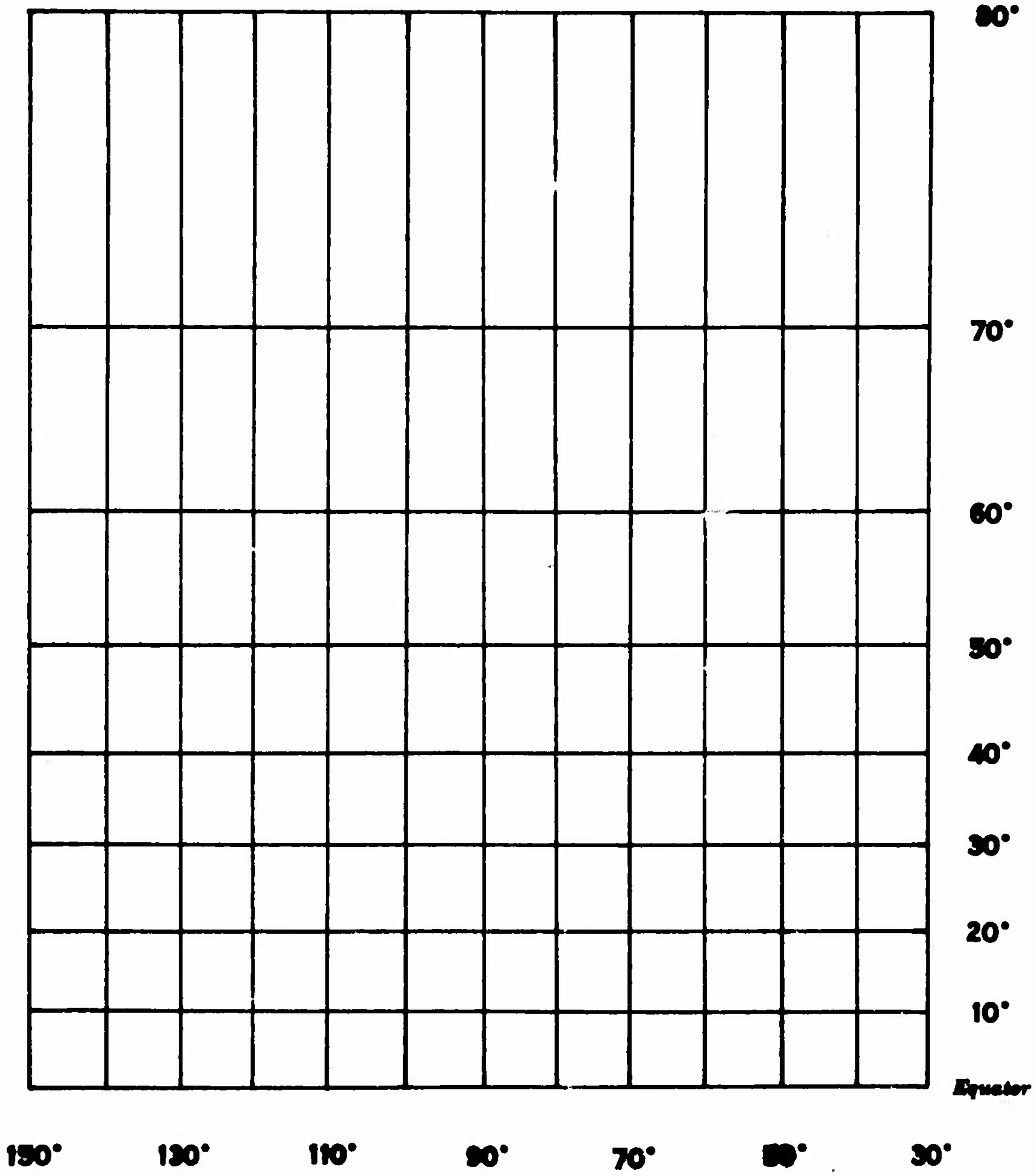
LONGITUDINAL DISTANCES (Centimeters)

30°00'	0.00000	80°00'	5.32620	120°00'	9.60716
40°00'	1.06524	90°00'	6.39144	130°00'	10.65240
50°00'	2.13048	100°00'	7.45668	140°00'	11.71764
60°00'	3.19572	110°00'	8.52192	150°00'	12.7828
70°00'	4.26096				

COMPUTED BY	DATE
M. G. Paradis	7 April 1967
CHECKED BY	**DATE**
M. J. Lohr, Jr. and R. W. Nance	7 April 1967

Figure 2

MERCATOR PROJECTION



APPROXIMATE SCALE 1:104,500,000 AT LAT. 00°00′

Figure 3

projections which show them as straight lines.

While considering both the advantages and disadvantages of the Mercator, as opposed to the numerous other projections available

TABLE 1 SCALE VARIATION IN FIGURE 3

LATITUDE	APPROXIMATE SCALE
80°	1:18,146,000
70°	1:35,741,000
60°	1:52,250,000
50°	1:67,171,000
40°	1:80,051,000
30°	1:90,500,000
20°	1:98,198,000
10°	1:102,912,000
Equator	1:104,500,000

to the navigator, one cannot help but conclude that it is the most suitable projection for use in the field of marine navigation.

VARIATIONS

There are two major variations of the Mercator Projection, both also being developed on a cylinder. The first and most important is the Transverse Mercator. The second and less frequently seen is the Oblique Mercator Projection.

TRANSVERSE MERCATOR PROJECTION

The Transverse Mercator, like the Mercator, may be visualized as being developed on a cylinder (see Figure 4), although

CYLINDER SECANT TO A SPHERE

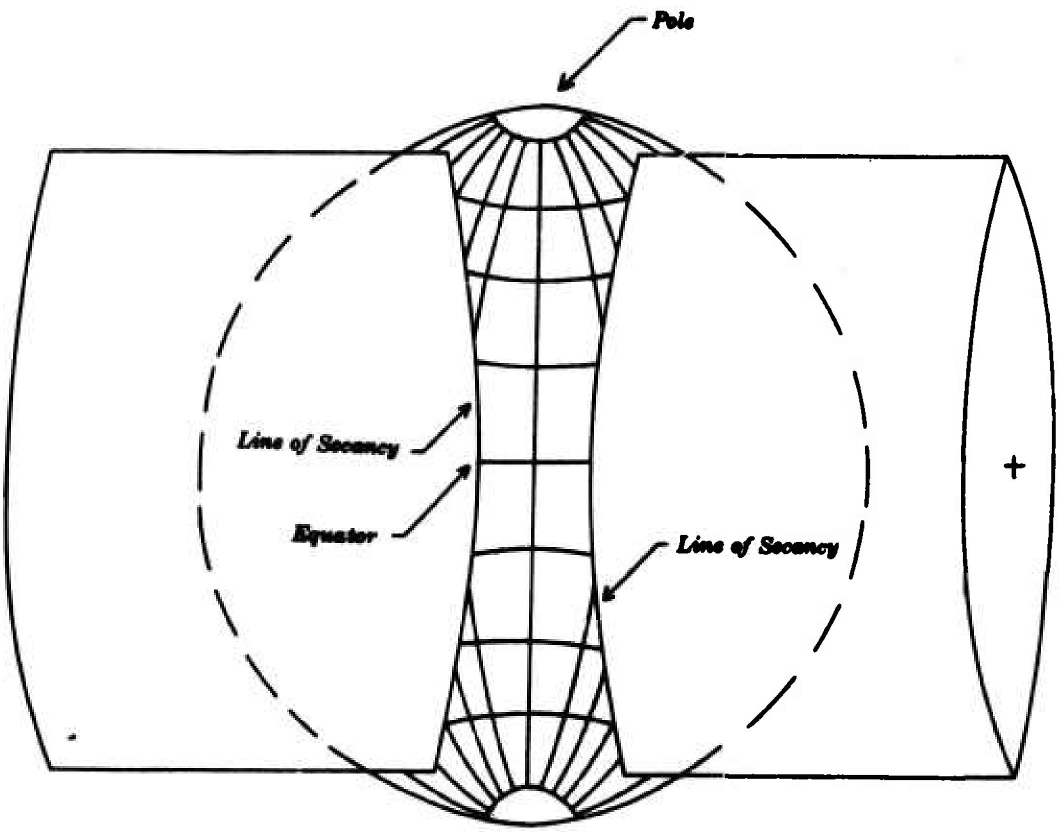


Figure 4

this cylinder has been rotated through 90° from its original position in Figure 1 and is secant to the earth's surface. The rotation shifts the line of tangency coincident with two opposite meridians in place of the equator. The axis of the cylinder lays in the equatorial plane instead of along the polar axis, while the point of view remains at the earth's center.

There are also numerous inherent advantages and disadvantages applicable to the Transverse Mercator. This projection has inherited all of the excellent qualities that the Mercator depicts along its equatorial belt. The first and foremost advantage of the Transverse Mercator is the marked reduction in scale variation over a relatively small area. By using a limited band along the lines of secancy the scale variation is evenly distributed and all but eliminated. Additional good features are that great circles approximate a straight line, area representation is vastly improved, and the projection retains the quality of conformality (parallels and meridians intersect at right angles). Among the disadvantages, the first to appear is the loss of the straight rhumb line property; secondly, it is not as easily constructed as the Mercator, although tables can be obtained; and third, this projection is not rectilinear, in that the parallels curve concavely toward the pole while the meridians curve concavely toward the central meridian, and thereby are more difficult to use. An example of the Transverse Mercator Projection is displayed in Figure 5.

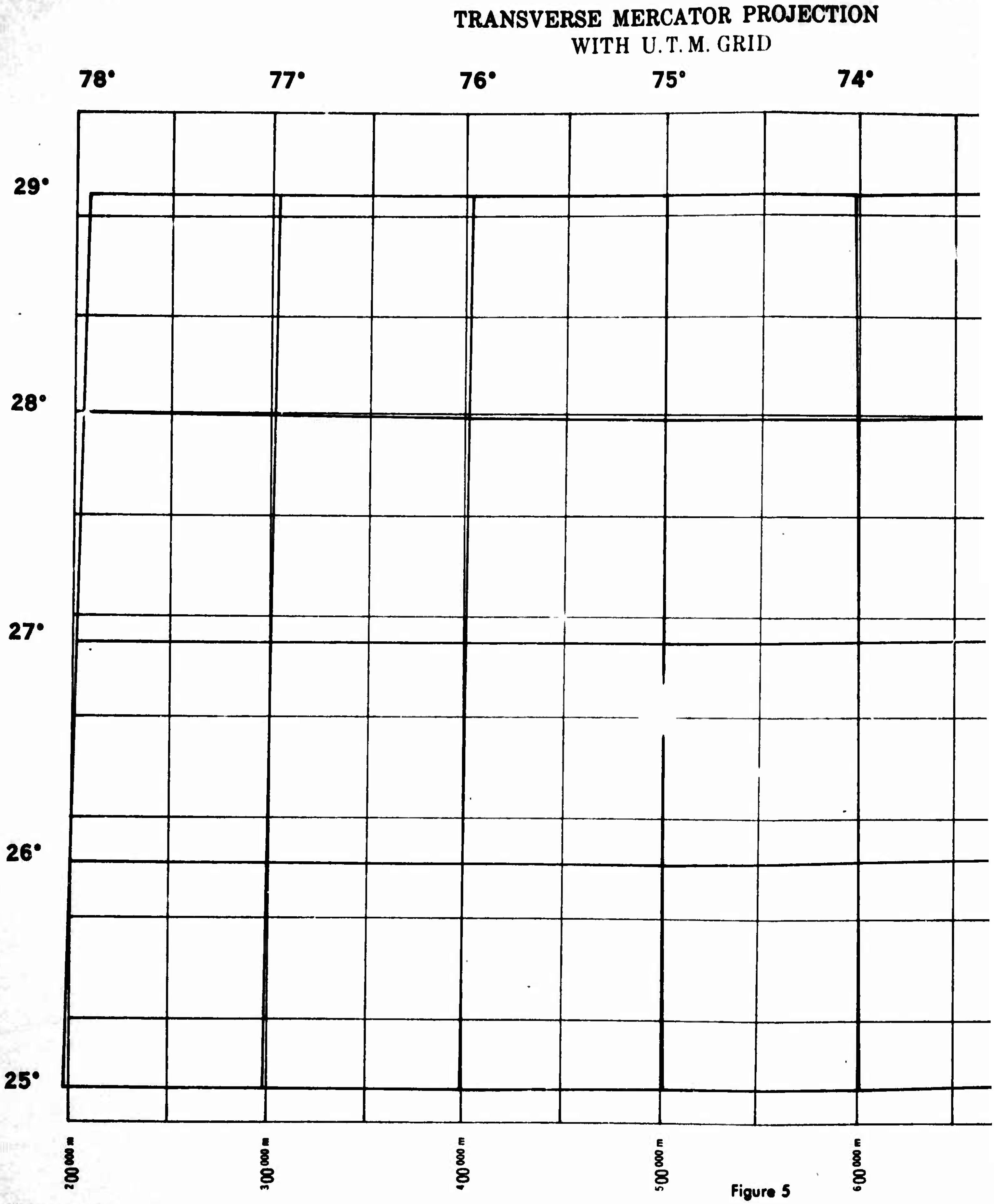

TRANSVERSE MERCATOR PROJECTION
WITH U.T.M. GRID
78°
77°
76°
75°
74°
29°
28°
27°
26°
25°
200 000 m
300 000 m
400 000 m
500 000 m
600 000 m

Figure 5

TRANSVERSE MERCATOR PROJECTION
WITH U.T.M. GRID

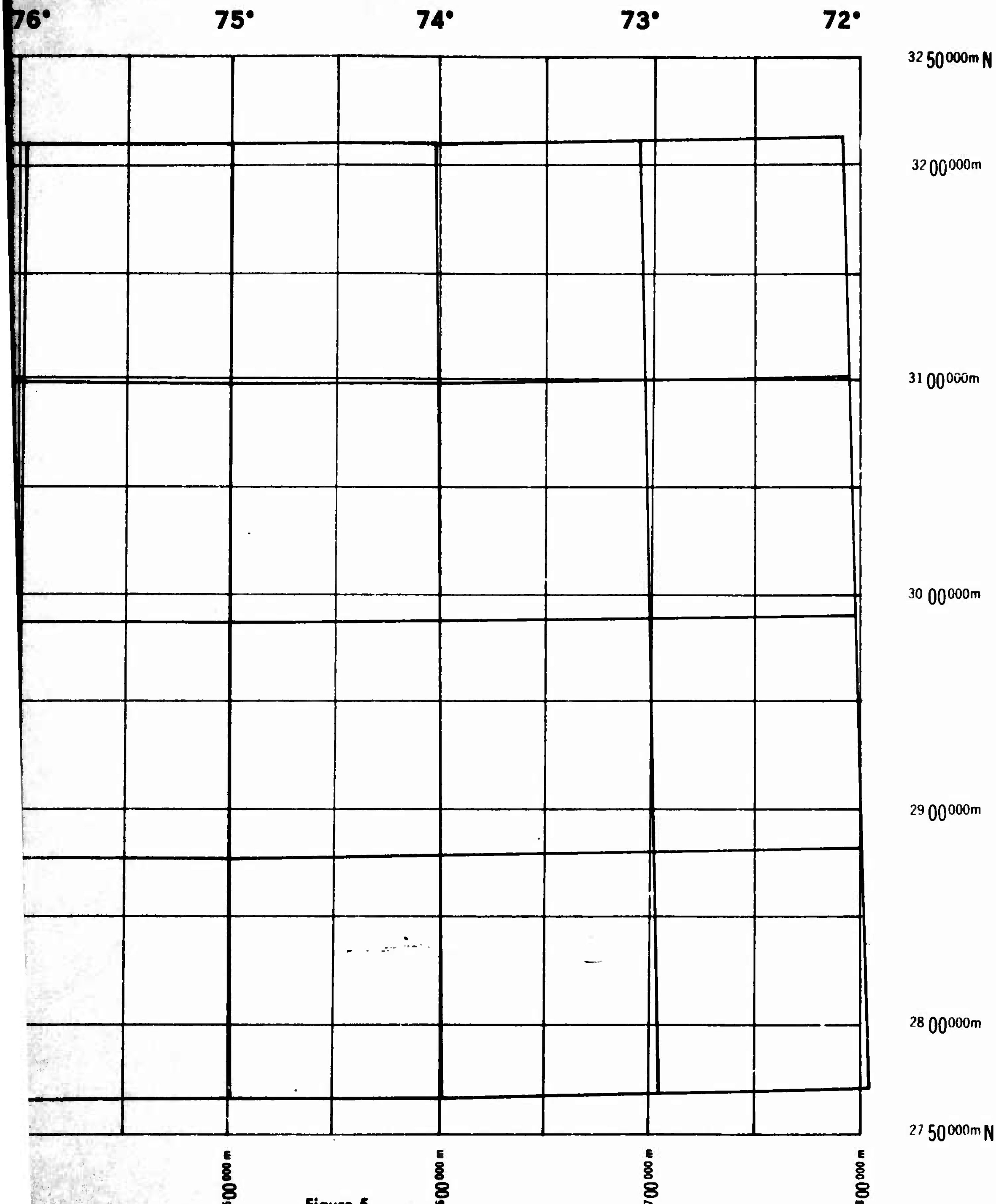


Figure 5

UNIVERSAL TRANSVERSE MERCATOR GRID (U.T.M.)

The U.T.M. is a rectilinear military grid utilizing the metric system and is primarily used for the fast accurate identification and referencing of points. It is usually overprinted on a projection (see Figure 5) and facilitates the use of elementary plane trigonometric functions in the calculations of bearings and distances.

The U.T.M. is based on a Transverse Mercator Projection, utilizing the extreme accuracy of the long narrow North-South strips along the central meridian of each of 60 zones encompassing the earth. The zones are limited to 6° widths from East to West and consecutively numbered 1 through 60 eastward from the 180th meridian. These zones are then further subdivided into 8° bands of latitude and lettered from C through X (omitting I and O), beginning at the southern practical limit of 80°S and proceeding to the northern limit of 84°N. This banding and zoning creates a pseudo-rectilinear net for locating areas on the earth'r surface.

Each U.T.M. grid zone maintains an orientation system of its own. The system is based on the metric system, an false origins (false easting and false northing). The false easting equals 500,000 meters and is coincident with the central meridian. All East-West measurements within the zone are referenced to the false easting. The false northing is coincident with the equator, which is given an arbitrary value of zero meters for the northern hemisphere, and 10,000,000 meters North for the southern hemisphere. All North-South measurements within the zone are referenced to the

false northing.

OBLIQUE MERCATOR PROJECTION

The Oblique Mercator, though less commonly used until the coming of the "Satellite Age", is another variation of the Mercator. It varies from the Mercator and the Transverse Mercator in that any great circle, except the equator or two opposite meridians, may be taken as the line of tangency in developing the surface. See Figure 6 for an example of a cylinder tangent along such a great circle.

As with the Transverse Mercator, the Oblique Mercator has inherited all of the good qualities that the Mercator displays along the line of tangency (equator). This projection utilizes a fictitious graticule offset from the network of geographic meridians and parallels. The Oblique Mercator manifests excellent representation of scale, area, and shape in a narrow band centered on the line of tangency. All important delineations, rhumb lines and great circles (excluding the line of tangency), are curved in this projection. The meridional reference lines are curved and the parallel reference lines are portrayed as sine curves. By the presence of numerous curved lines it is readily understandable why this non-rectilinear projection is difficult to construct and use.

This projection is usually tailor-made for satellite tracking or following great circle routes, which require only a relatively narrow band on either side of the line of tangency (a great circle).

CYLINDER TANGENT ALONG A GREAT CIRCLE OTHER THAN THE EQUATOR OR MERIDIANS

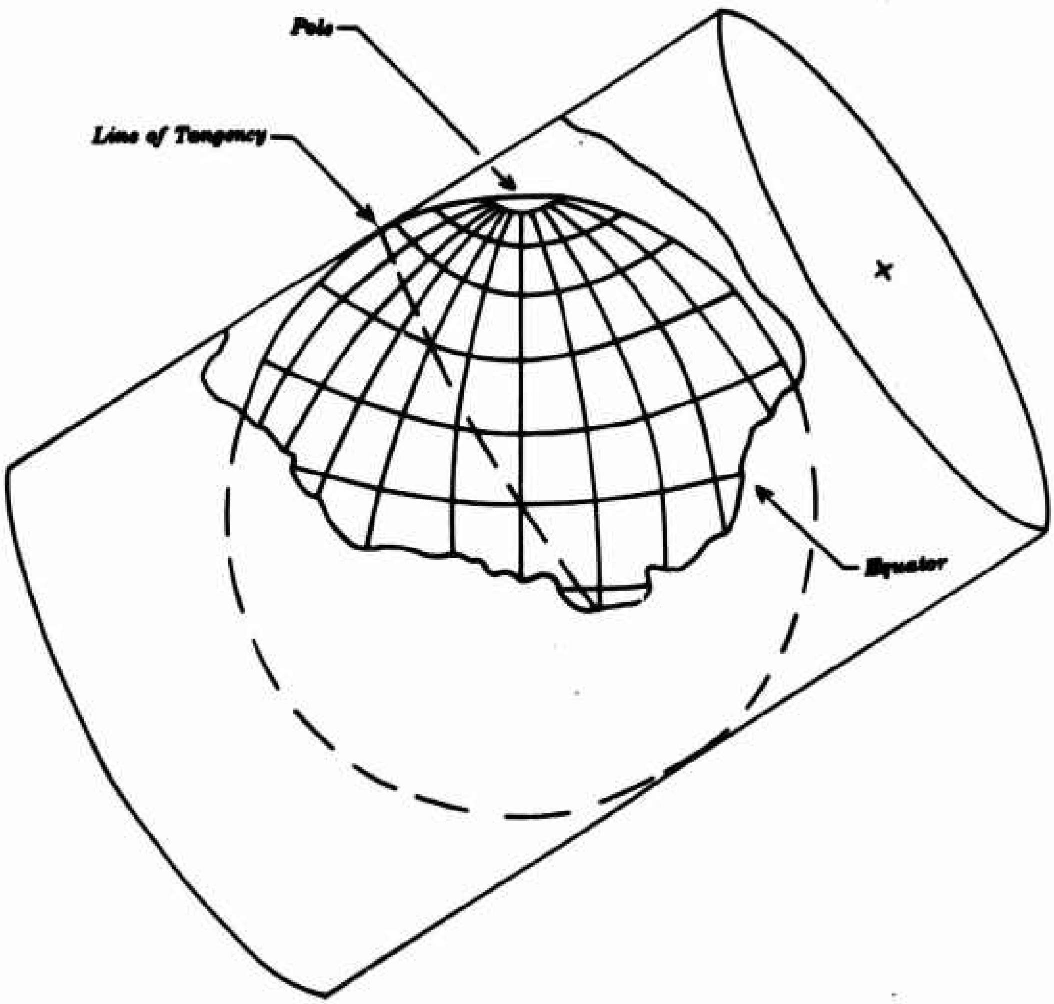


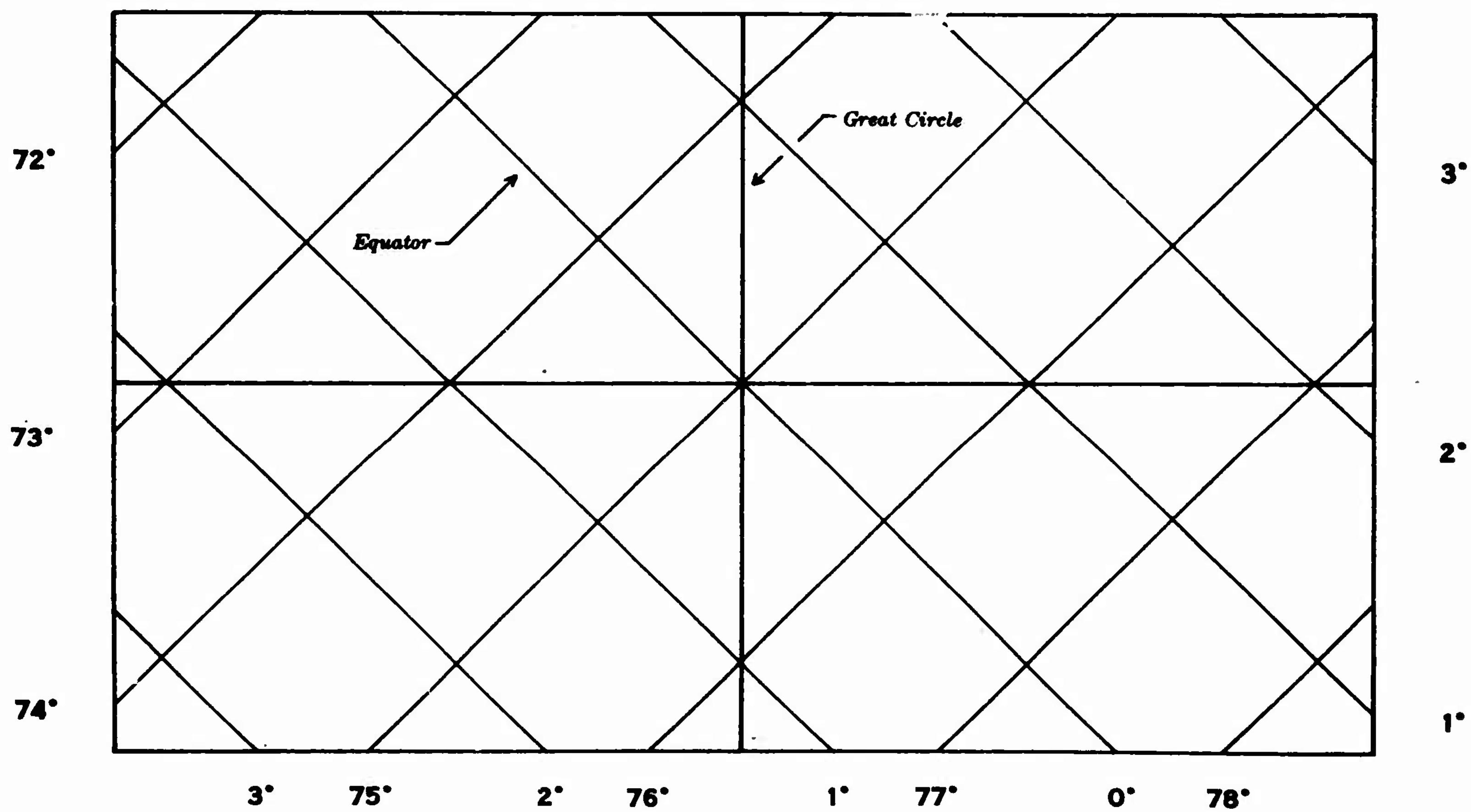
Figure 6

An example of an Oblique Mercator Projection is shown in Figure 7.

* * * * *

It is believed that the necessary basic points regarding the Mercator Projection and its variations have been presented to meet the intent of this report. It is also hoped that sufficient interest has been created so that the apprentice cartographer and cartographic technician alike will further delve into the realm of projections.

OBLIQUE MERCATOR PROJECTION



APPROXIMATE SCALE 1:4,000,000

Figure 7

SELECTED GLOSSARY

Chart: A map intended primarily for navigational use.

Conformality: A unique property of conformal projections where small figures on the earth's surface retain their shape on a map.

Developable Surface: A surface that can be laid out perfectly flat, e.g., the surface of a plane, cylinder, or cone.

Equator: The line on the earth's surface created by the intersection of that surface with a plane passing through the center of the earth and perpendicular to the polar axis.

Gnomonic Projection: A projection on a plane tangent to the earth with the point of view (origin of projection) at the center of the earth. This is the only projection on which great circles appear as straight lines.

Graticule: The network of lines on a map or chart representing parallels or meridians.

Great Circle: A line on the surface of the earth created by the intersection of that surface and a plane passing through the center of the earth.

Grid: Two sets of mutually perpendicular lines dividing a map or chart into squares or rectangles to allow location of points through a system of rectangular coordinates.

Large Scale: A scale involving a relatively small reduction in size (1:75,000 and larger).

Latitude: The angle at the center of the earth lying between the equatorial plane and a radius to the point of interest.

Longitude: The angle at the center of the earth lying between two meridional planes, that of the origin (Prime Meridian) and that of the point of interest.

Loxodrome: See Rhumb line.

Map: A representation of a portion of the earth on a plane surface showing orientation, symbolization, and relative size (scale).

Map Projection: The network of lines of latitude and longitude projected geometrically or mathematically from the earth's surface onto a plane surface.

Medium Scale: A scale involving a relatively moderate reduction in size (between 1:75,000 and 1:600,000).

Mercator Projection: A conformal cylindrical map projection in which the surface of the earth is developed on a cylinder tangent along the equator, with the expansion of the meridians at the same ratio to that of the parallels with increasing latitude.

Meridian: A reference line on the earth's surface marked by the intersection of that surface and a plane containing the polar axis. A meridian is a great circle.

Nautical Chart: A chart intended primarily for marine navigation.

Oblique Mercator Projection: A map projection very similar to the Mercator Projection, but with the cylinder rotated between 0° to 90°, so that the cylinder is tangent along any great circle (excluding a meridian or the equator).

Parallel: A reference line on the earth's surface marked by the intersection of that surface and a plane perpendicular to the polar axis. A parallel is a small circle.

Polar Axis: The straight line which connects the poles of the earth.

Pole: The two points of intersection of the surface of the earth with its spin axis.

Rhumb Line: A loxodrome, or line on the surface of the earth intersecting all meridians at the same angle (curves toward the poles as constant course).

Scale: The ratio between the linear distance on a map or chart and the actual distance represented.

(Map Scale)(Map Distance) = (Ground Scale)(Ground Distance)

Small Scale: A scale involving a relatively large reduction in size (smaller than 1:600,000).

Transverse Mercator Projection: A map projection very similar to the Mercator Projection but with the cylinder rotated through 90°, so that the cylinder is secant to the surface of the earth.

Universal Transverse Mercator Grid (U.T.M.): A military grid based upon a Transverse Mercator Projection.

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